HARMAN

Development of a Method for Testing House-Heating Boilers

Mechanical Engineering

M. E.

1906

# DEVELOPMENT OF A METHOD FOR TESTING HOUSE-HEATING BOILERS

BY

John James Harman, B.S., 1902

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# THESIS

FOR THE DEGREE OF MECHANICAL ENGINEER

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GRADUATE SCHOOL
OF THE
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN JAMES HARMAN, B. S.

ENTITLED DEVELOPMENT OF A METHOD FOR TESTING HOUSE-HEATING BOILERS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Mechanical Engineer

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

C O N T E N T S

# DEVELOPMENT OF A METHOD FOR TESTING HOUSE-HEATING BOILERS

MECHANICAL ENGINEERING LABORATORY

UNIVERSITY OF ILLINOIS

URBANA, ILLINOIS

1906.

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## INTRODUCTION

The Engineering Experiment Station of the University of Illinois is preparing to conduct an extensive series of experiments on the different coals used in the State of Illinois, in order to determine the most economical methods of utilizing them.

A sufficient number of tests will be run on each coal to determine the conditions of firing best suited to the particular coal under consideration. It is expected that the results of these tests will be of great value to the users of coal throughout the state, not only in determining which coals are best suited for certain purposes, but also by indicating the proper method of firing in order to obtain the best results from any particular kind of coal.

Tests of fuels will be made: (a) under power plant boilers; (b) in house-heating boilers; (c) in gas producers; (d) to determine their chemical composition and heating values.

The fact that Illinois is one of the leading states of the Union both in coal consumption and coal production

establishes beyond a doubt the desirability of such tests. Then again, while the question of the ultimate exhaustion of our American coal fields need not at the present time give us serious concern, it must nevertheless eventually be faced, and this fact makes it imperative for the nation to foster its fuel supply by utilizing it in the most economical manner possible. That the seriousness of the fuel question is realized by a great many people is evidenced by the movement which is now on foot to obtain from the government the privilege of manufacturing denaturized alcohol without taxation. On February 6, 1906, the Hon. James Wilson, Secretary of Agriculture, in the speech before the Committee of Ways and Means, House of Representatives, made the following remarkable statement: "The time will certainly come when the world will have to look to Agriculture for the production of its fuel, its light, and its motive power".

## SCOPE OF THESIS

This thesis has to do with the design of a convenient apparatus for conducting a series of coal tests in house-heating boilers, and the preparation of an outline for the method of testing. Although the plant was in operation every day for a period of about two weeks, only one complete 24-hour test was obtained. The rest of the time was devoted to necessary changes and adjustment of apparatus.

## CONDITIONS GOVERNING DESIGN OF APPARATUS

The observations which are necessary in a test of this kind are in all respects similar to those which are taken

in an ordinary power plant boiler test. Then, in view of the fact that a great number of tests are to be run with this apparatus, it was exceedingly desirable to reduce the labor of conducting the tests to a minimum. This was accomplished by making the apparatus as nearly automatic as possible, so that a test might be conducted by one man, instead of requiring three or four as it does ordinarily.

Two features, which it was especially desirable to have automatic, were the weighing of the feed water and the feeding of the boiler. The method which was adopted was to condense the steam generated, weigh it by means of a weighing meter, and return it to the boiler by means of a return trap.

It was also desirable that the apparatus should be mounted on a framework entirely separate from the boiler, in order that the boiler might be disconnected, moved, and another set in its place without any serious changes in the apparatus. This latter provision makes it possible to conduct comparative tests on the same coal, in order to determine the effect on economy of different proportions of grate area to heating surface and of different arrangements of the heating surface.

## DESCRIPTION OF APPARATUS

The apparatus for conducting these tests is located near the center of the south half of the main room in the Mechanical Engineering Laboratory at the University of Illinois. Fig. I is a general floor plan. Figs. II and III

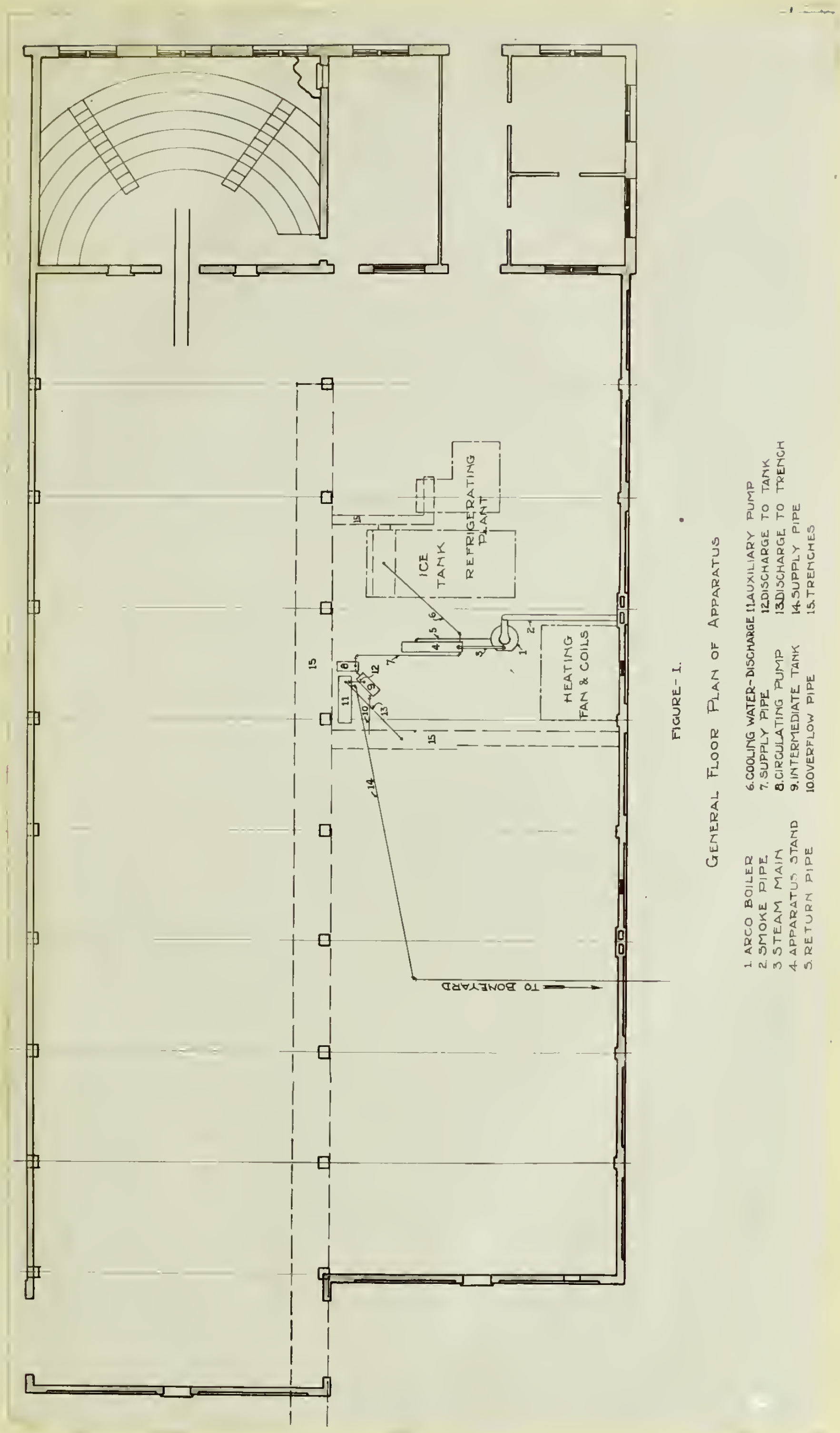

REFRIGERATING PLANT
ICE TANK
HEATING FAN & COILS
TO BONEYARD
FIGURE-I.
GENERAL FLOOR PLAN OF APPARATUS
1 ARCO BOILER
2 SMOKE PIPE
3 STEAM MAIN
4 APPARATUS STAND
5 RETURN PIPE
6 COOLING WATER-DISCHARGE
7 SUPPLY PIPE
8 CIRCULATING PUMP
9 INTERMEDIATE TANK
10 OVERFLOW PIPE
11 AUXILIARY PUMP
12 DISCHARGE TO TANK
13 DISCHARGE TO TRENCH
14 SUPPLY PIPE
15 TRENCHES

FIGURE I.

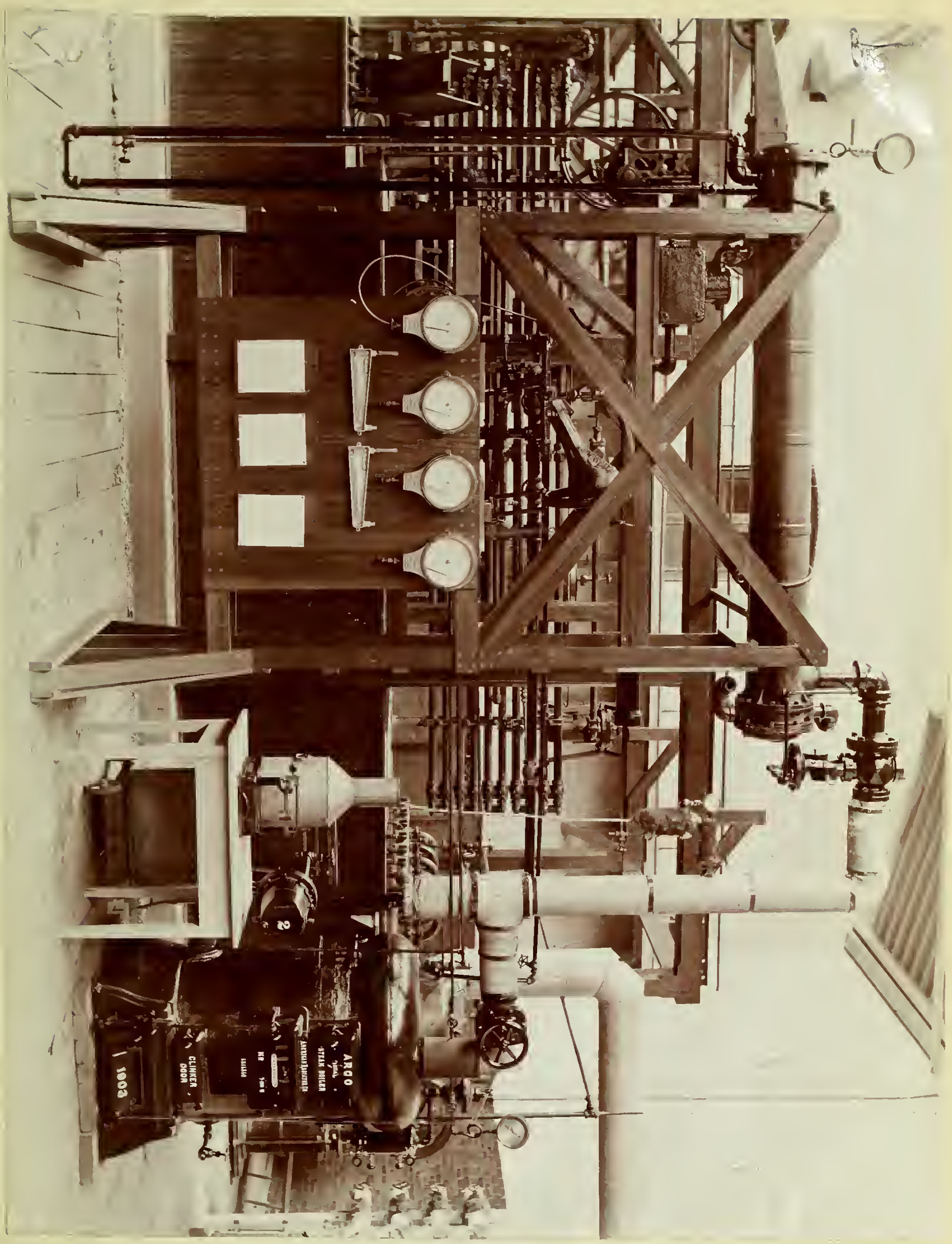



FIGURE II.

FIGURE III.

show front and rear views of this apparatus. The apparatus for handling the circulating water of the condenser had, however, been moved for use on other tests before the photographs were taken.

This apparatus occupies a floor space of about 30 square feet, and consists of the following:-

(A) Arco Steam Boiler

(B) Wheeler Condenser with Auxiliaries

(C) American District Steam Co., Water Meter No. 555

(D) Bundy Steam Trap

(E) Steam Separator

(F) Steam Trap

(G) Calorimeter

(H) Piping

(I) Gauges

(J) Thermometers

(K) Weighing tanks and Scales

(L) Sampling Cans

(M) Flue gas Analysis

(A) The Arco Steam boiler installed with this apparatus was manufactured by the American Radiator Co. Its leading dimensions are as follows:-

| | | |
|---|---|---|
| 1. | Catalogue No.------------------------------ | 1-28-S |
| 2. | Serial No.-------------------------------- | 5866 |
| 3. | Rated capacity, radiating surface, square feet | 800 |
| 4. | Height over all--------------feet, inches | 5-10 1/4 |
| 5. | Height of water line---------feet, inches | 4 - 8 |
| 6. | Floor space ---------------- square feet | 12 |

| | |
|---|---|
| 7. Size of fire door ---------------- inches | 9 5/8x18 |
| 8. Height of fire door above grate--- inches | 14 |
| 9. Area of grate (circular)----- square feet | 4 |
| 10. Fuel capacity, usually to center of feed door ------------------------------ pounds | 200 |
| 11. Height of furnace ---------------- inches | 22 1/2 |
| 12. Approximate width of air space in grates, inches | 3/8 |
| 13. Proportion of air space to entire grate surface ---------------------- per cent | 50 |
| 14. Area of chimney(8" x 16")-----square feet | .89 |
| 15. Height of chimney above grate ----- feet | 35 |
| 16. Least flue area in boiler---- square feet | .47 |
| 17. Area of flue connecting to chimney, square feet | .55 |
| 18. Length of flue connecting to chimney-feet | 20 |
| 19. Kind of draft --------------------------- | natural |
| 20. Water heating surface in direct contact with flames or fire pot surface, square feet | 18.8 |
| 21. Indirect water heating surface, square feet | 19.3 |
| 22. Superheating surface -------- square feet | 5.3 |
| 23. Total surface---------------- square feet | 43.4 |
| 24. Proportion of direct surface to total surface ---------------------- per cent | 43 |
| 25. Ratio of total heating surface to grate surface ---------------------------------- | 10.8 to 1 |
| 26. Ratio of minimum draft area to grate surface ------------------------------------- | 1 to 8.5 |

Fig. IV shows an exterior view of the furnace, while Fig. V shows the construction of the grate, and Figs. VI, VII and VIII show the arrangement of the heating surface. These


ARCO
STEAM BOILER
PATENT APPLIED FOR
Nº 1-34-S-
CLINKER
DOOR
1905

FIGURE IV.

20


FIGURE V.

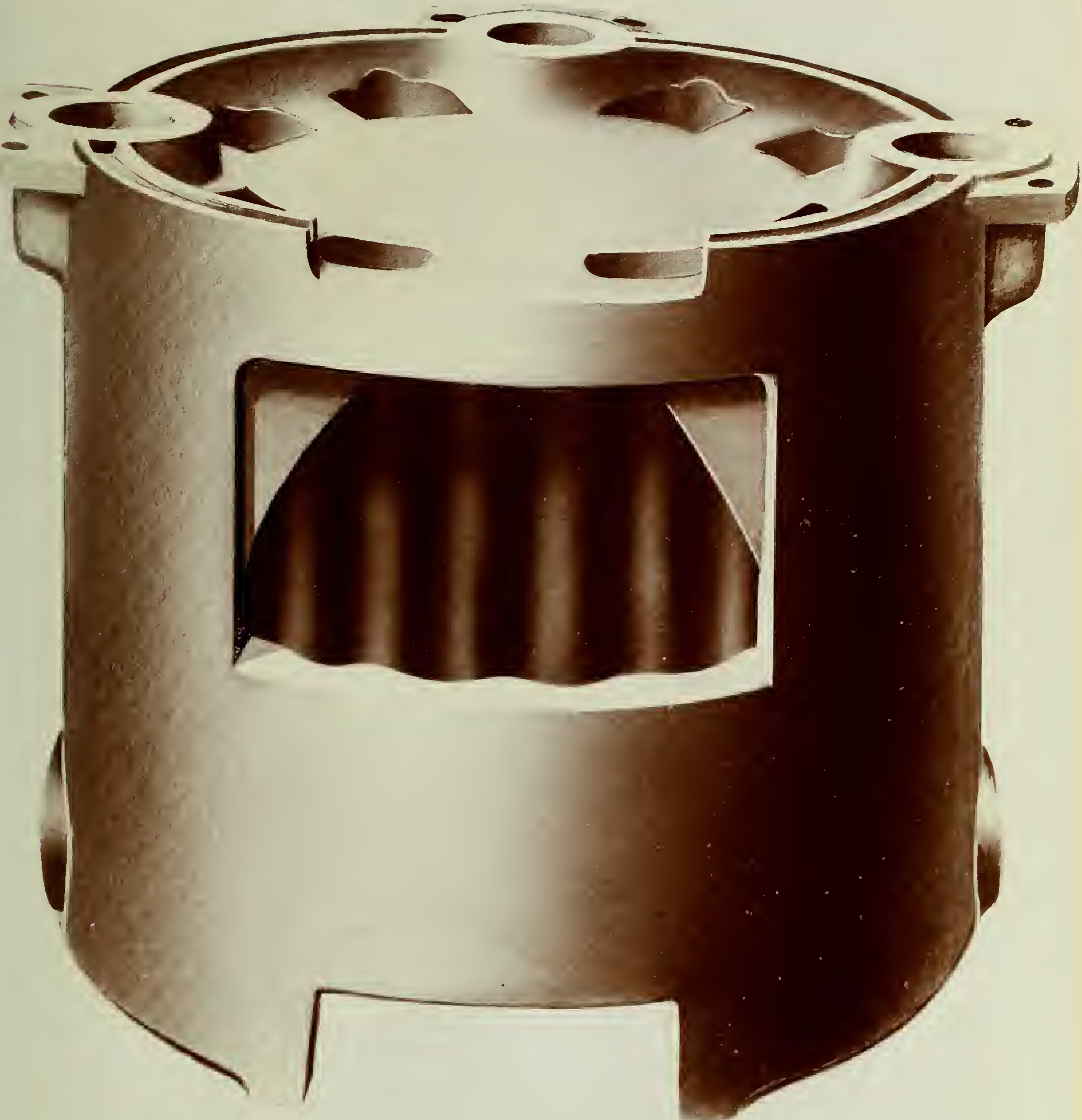


FIGURE VI.

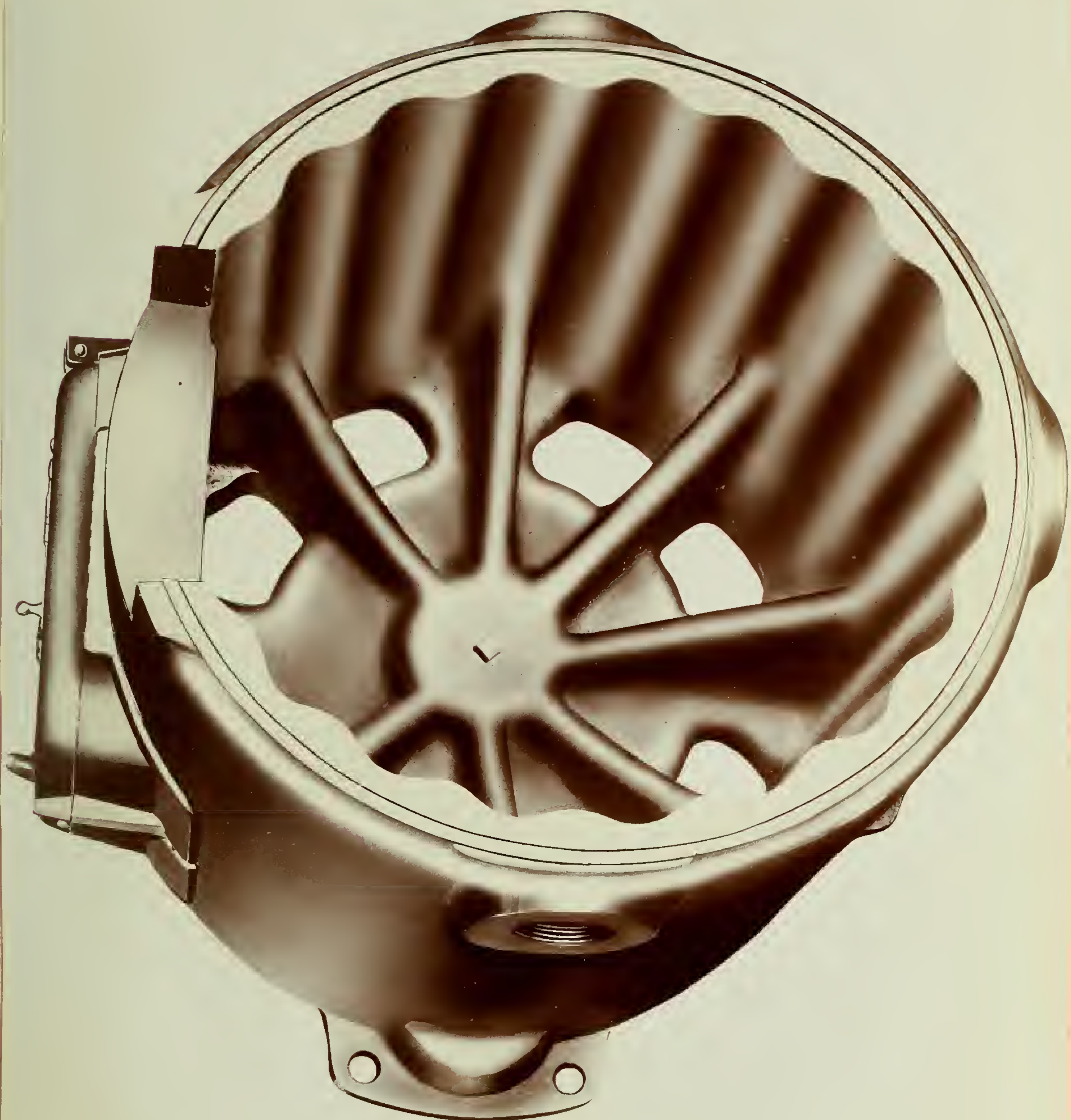


FIGURE VII.

FIGURE VIII.

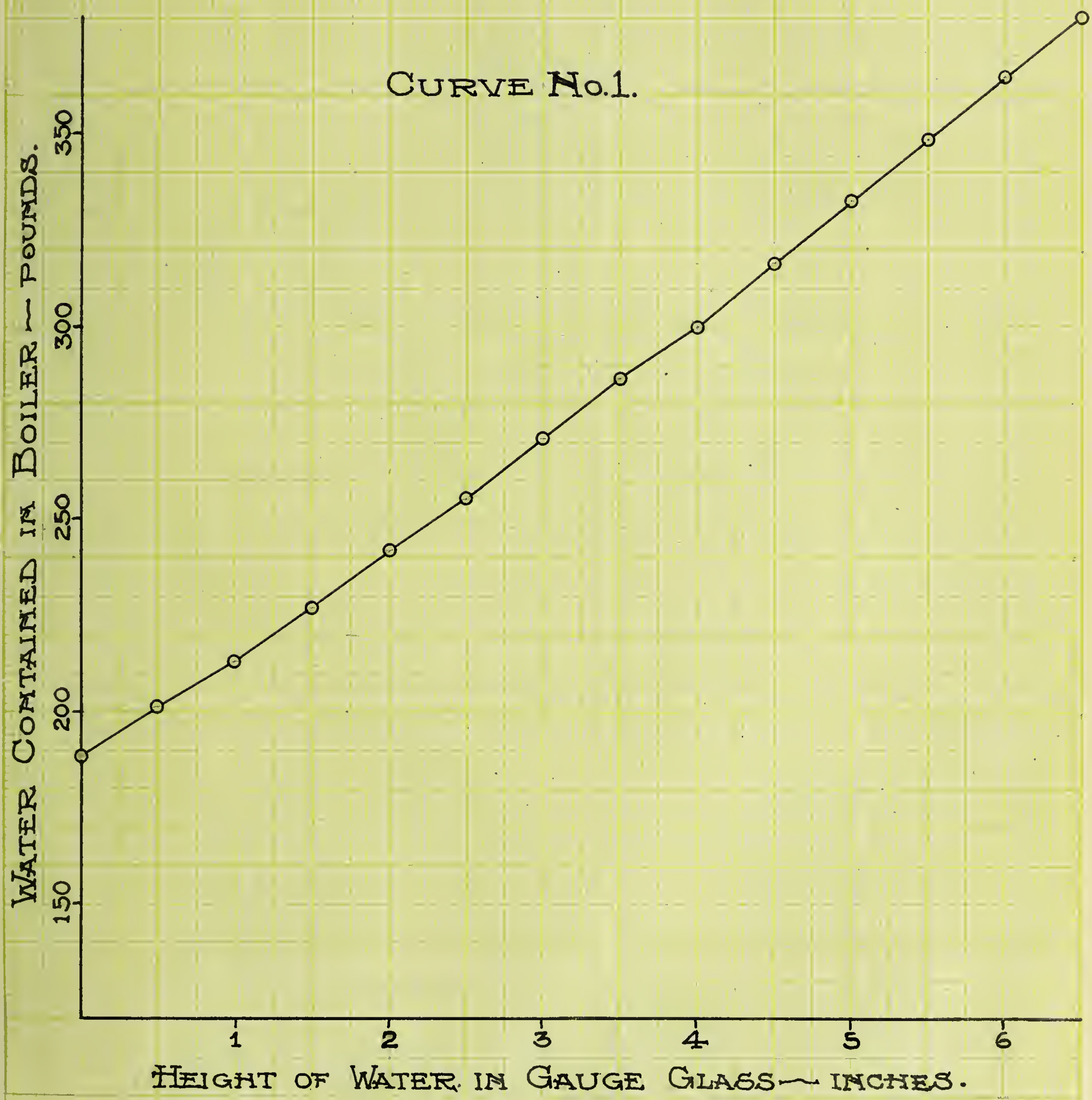
photographs were furnished by the American Radiator Company. Through a mistake no photograph of the top section was obtained, however the arrangement of heating surface is similar to that in the other sections.

Curve No. 1 is a calibration curve for the boiler, and shows the amount of water contained in it for each inch on the gauge glass. The data for this curve were obtained by drawing out the water through the blow-off and weighing it. Before the water was drawn off, the boiler was heated up in order to obtain the data under actual working conditions.

There is, however, a possible source of error in determinations of the amount of water in boiler by readings on the gauge glass. This error is due to rise of the water line on account of evaporation of water below the surface. Circulation of the water, in this type of boiler, probably affects the level of the water in gauge glass very little. The amount of this error seemed to range from 0 to 2 or 2 1/2 inches, depending on the rate of evaporation.

One feature of this boiler worthy of mention is the large size of the fire pot. The advantages gained by this are: (1), a large percentage, 43%, of the total heating surface is in direct contact with the fire; (2), it affords a larger combustion chamber for consuming the volatile matter before it comes in contact with the comparatively cold water-backed surfaces.

(B) The Wheeler Condenser is used for condensing the steam generated by the boiler. It is of the ordinary double tube type and has the following dimensions:-



CURVE No.1.
WATER CONTAINED IN BOILER — POUNDS.
150
200
250
300
350
1
2
3
4
5
6
HEIGHT OF WATER IN GAUGE GLASS — INCHES.

| | | | |
|---|---|---|---|
| 1. | Diameter | inches | 10 |
| 2. | Length | feet | 8 |
| 3. | Number of tubes | | 52 |
| 4. | Outside diameter of inner tube | inches | 3/4 |
| 5. | Outside diameter of outer tube | inches | 1 1/8 |
| 6. | Total condensing surface | square feet | 60 |
| 7. | Size of water and vacuum connections | inches | 2 |
| 8. | Size of steam inlet | inches | 3 |
| 9. | Capacity, in steam condensed per hour under ordinary conditions | pounds | 1000 |

In test No. 1 the circulating water was taken from the "Boneyard", a surface drain which lies about 50 feet south of the Mechanical Engineering Laboratory. The rate of condensation was adjusted by regulating the speed of the circulating pump. The pump was a 4 1/2 x 2 1/2 x 4 Worthington duplex. Considerable trouble was experienced at the outset with this part of the apparatus, and several changes were made before satisfactory results were obtained. An attempt was first made to condense the steam by circulating brine, from the ice tank of the refrigerating plant, see Fig. I, through the condenser, and to keep the temperature of the brine down by running the ice machine. It was found, however, that the capacity of the ice machine was not equal to the task. This scheme was then abandoned, and the circulating water was obtained from the "Boneyard", as before stated. But after this change was made, trouble was again encountered in another form. The suction pipe of the circulating pump was about 75 feet long and had a rise of about 8 feet, and it

was found to be impossible to maintain the suction when the pump was running at very slow speeds. This difficulty was overcome by installing an auxiliary pump, which raised the water from the "Boneyard" and discharged it into a tank that was slightly elevated above the level of the circulating pump. This tank was connected with the suction of the circulating pump, and was also provided with an overflow which carried away any excess of water. No further trouble was experienced and it was found that the rate of condensation could be very nicely adjusted by simply regulating the speed of the circulating pump.

It was the intention to carry a slight pressure in the condenser, and, in order to prevent the escape of uncondensed steam into the atmosphere, the discharge from the condenser was sealed by a water leg 11 feet long. This water leg will hold any pressure up to $\frac{11}{2.3} = 4.8$ pounds per square inch.

In view of the fact that the pressure in the condenser was quite likely to rise above this amount, unless it was closely watched, with a resulting loss of uncondensed steam to the atmosphere, it was deemed advisable to place a pressure reducing valve in the steam line. An Eclipse vacuum-pressure regulating valve, manufactured by the John Davis Company of Chicago, was accordingly installed. No difficulty was experienced is so setting this valve as to fix the upper limit of pressure at 3 pounds. An exterior view of the valve is shown in Fig. IX.

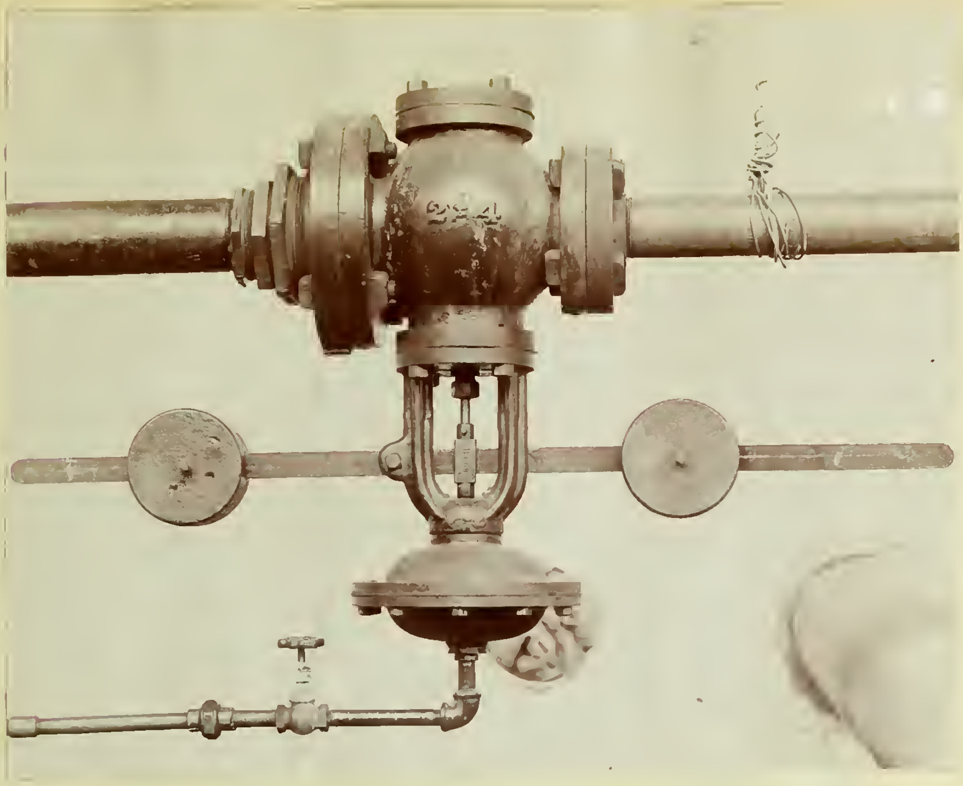


FIGURE IX.

(C) An American District Steam Co. Water Meter No. 555, is used to measure the wat r passing from the condenser back to the boiler. Figs. X, XI and XII show the exterior appearance and construction of this meter quite clearly. It is evident from these figures that the registering device is actuated by a motion of the buckets which is produced by a certain definite weight of water. Consequently, this meter really weighs the water instead of measuring it, and a variation in the temperature of the water would not affect at all the accuracy of the meter.

However, it was found that the rate of flow of the water through the meter did very seriously affect the accuracy, on account of the leakage which occured while the buckets were dumping. In order to prevent these inaccuracies in the

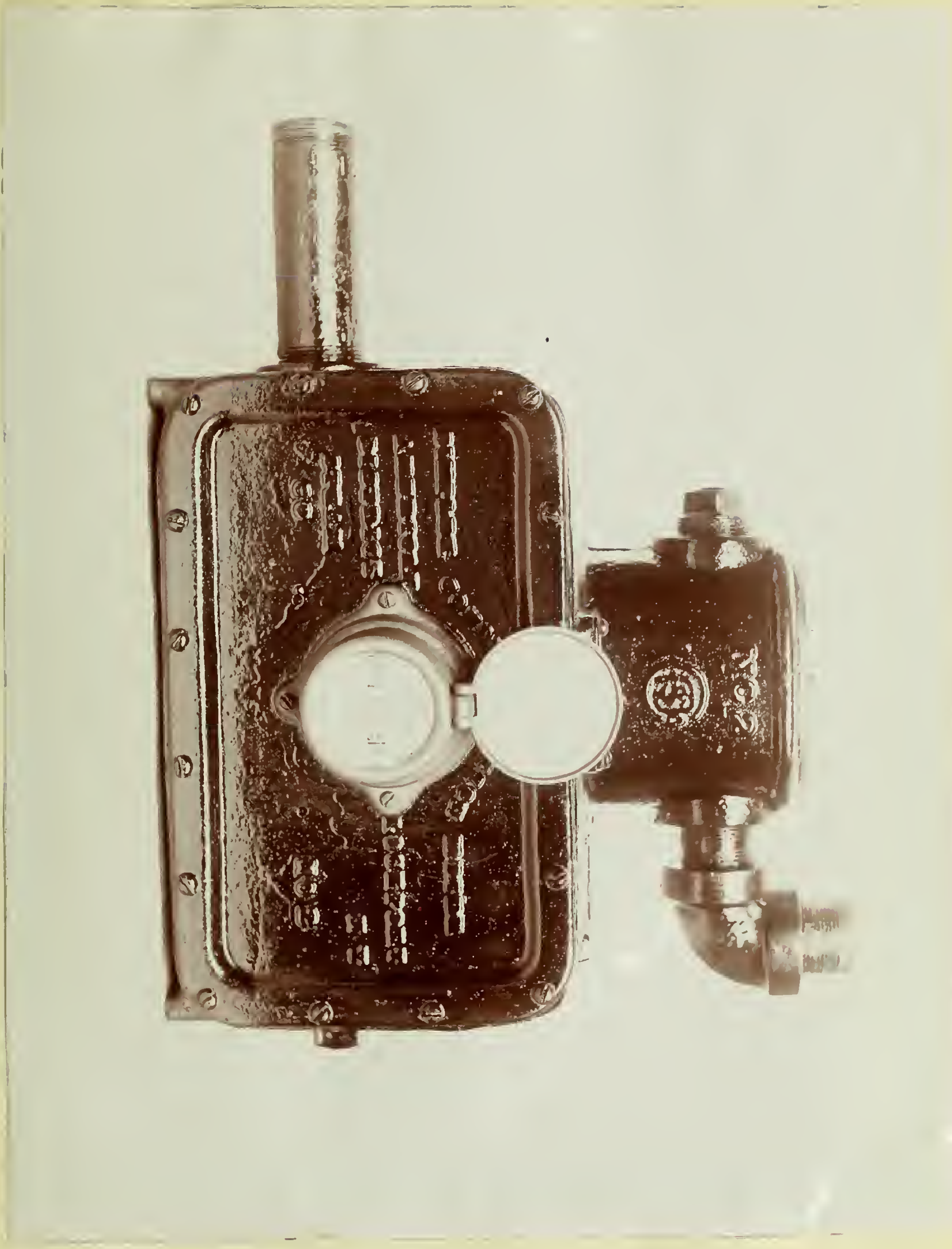


FIGURE X.

FIGURE XI.

FIGURE XII.

meter readings, it was necessary to devise some means of maintaining the rate of flow uniform. This was accomplished by discharging the water from the condenser into a receiver above the level of the meter. The receiver, which will be called receiver No. 1, contained a siphon which was made of a piece of 1/4-inch pipe bent as shown in Fig. XIII. By this device the water is collected in the receiver until the siphon is flooded, whereupon all of the water above the end of the short leg of the siphon is discharged at practically a uniform velocity. After this quantity of water has been discharged, the flow will cease suddenly and the water will again be collected until the siphon is flooded.

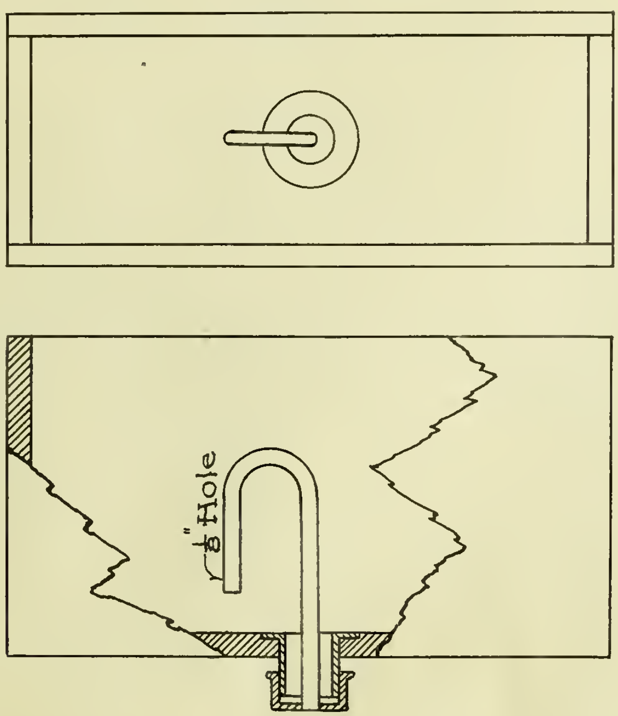



FIGURE XIII.

The meter was carefully calibrated in connection with the regulating receiver, and the following results were obtained:-

CALIBRATION OF METER NO. 555

MADE AT MECHANICAL ENGINEERING LABORATORY

UNIVERSITY OF ILLINOIS

Made by HARMAN and STANLEY

| METER READINGS | | ACTUAL WEIGHT | | Error in per centage of meter read'g Low. |
|---|---|---|---|---|
| Readings | Diff | Gross | Net | |
| 507780 | | 66.1# | | |
| 800 | 20 | 90.3 | 24.2 | 21.0 |
| 820 | 20 | 114.2 | 23.9 | 19.5 |
| 840 | 20 | 138.5 | 24.3 | 21.5 |
| 860 | 20 | 162.5 | 24.0 | 20.0 |
| 880 | 20 | 186.6 | 24.1 | 20.5 |
| 900 | 20 | 210.5 | 23.9 | 19.5 |
| 920 | 20 | 234.5 | 24.0 | 20.0 |
| 940 | 20 | 258.4 | 23.9 | 19.5 |
| 960 | 20 | 282.4 | 24.0 | 20.0 |
| | | | Aver. | 20.2 |

During the trials the rate of flow into the receiver was varied between wide limits. The maximum difference in readings was evidently 21.5 - 19.5 or 2%, and as these errors are compensating, the actual meter reading increased by 20% should be a very accurate determination of the amount of water fed to the boiler.

One feature of this meter which gave some trouble at first was the fact that the outlet had to be perfectly free from pressure at all times, so that no water could back up into the meter. It is easily seen from the construction, that the presence of any considerable quantity of water in the weighing chamber would float the buckets and destroy their weighing action.

(D) The Bundy return steam trap was decided upon as the simplest and most effective means of returning the water from the meter to the boiler. A rather serious difficulty was encountered, however, from the fact that the smallest Bundy return trap in the market had a capacity of 1250 pounds of water per hour, while the maximum amount to be handled in this case was only about 200 pounds per hour. On account of this difficulty and the high price of the return traps, a No. 76 Bundy separating trap, which belonged to the department of Mechanical Engineering, was converted into a return trap. The actual expense of making the change was only a few dollars, but considerable time was devoted to it before satisfactory operation was obtained.

Figs. XIV and XV show sectional views of the two different types of traps. The following catalogue descriptions give a general idea of their principles of operation:-

"The return trap (Fig. XIV) consists of a cast-iron receiving bowl (A), supported on a yoke and frame by two trunnions, with freedom to move up and down as it fills and discharges. The water enters the feed trunnion (D), shown in the sectional view of the yoke, passes into the bowl, which when full overbalances the ball (E) on the horizontal lever (F). Thus released, it drops and the projecting ring (G) pulls upon the valve stem (H) opening the valve (I) and admitting steam from the boiler. The pressure on trap and boiler now being equal, and the trap being located 3 feet or more above the water line, the water in consequence of seeking a lower level passes from the trap into the boiler.

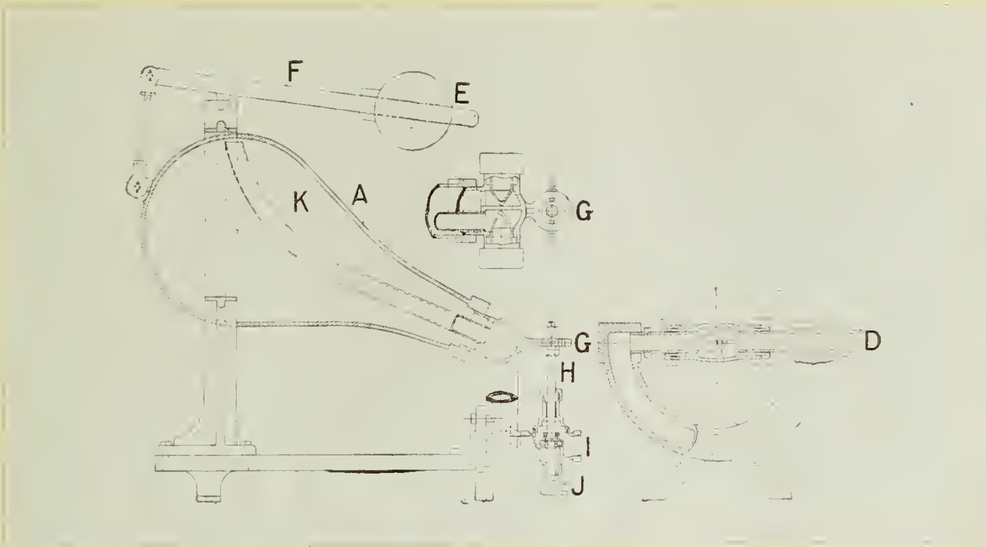



FIGURE XIV.

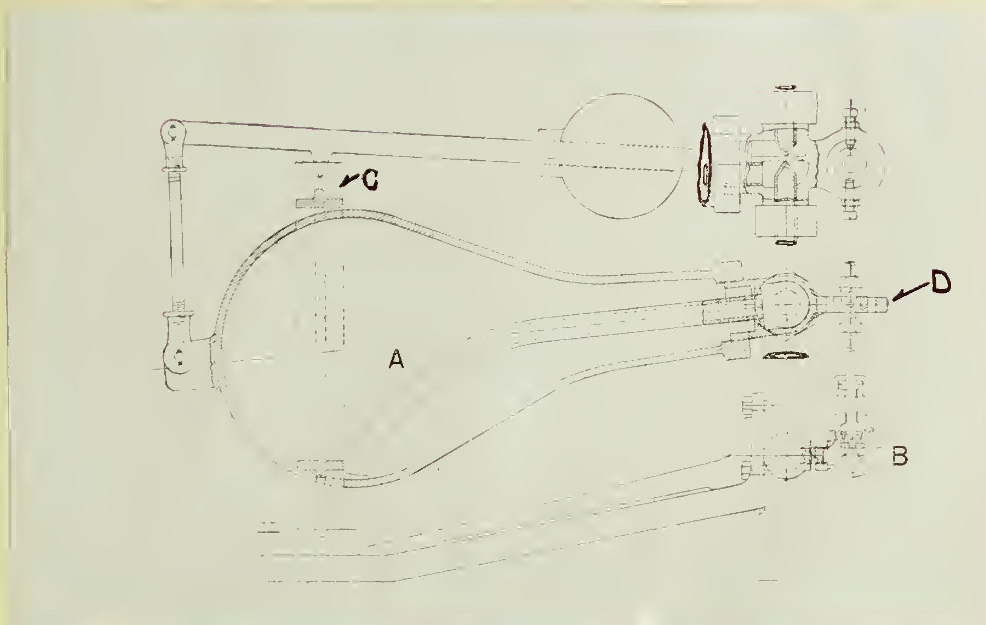



FIGURE XV.

When the trap bowl is empty the weight on the lever pulls it back into its original or filling position and closes the steam valve. At the same time it opens the valve (J) and exhausts the steam remaining in the bowl, as well as the air. The steam to enter the trap passes through the interior curved pipe (K) and is discharged on the surface of the water".

"The general principle of construction of the separating trap (Fig. XV) is the same as that of the return trap, but the process of operation differs in some respects. With this trap the water enters through the feed trunnion, which occupies the same position as that on the return trap, passes into the receiving bowl and fills it; the bowl drops and opens the discharge valve (B) by lifting the valve disc from its seat as shown in the cut. The pressure on the coils, or apparatus which the trap may be draining, being exerted on the surface of the water in the bowl, forces the water out through the pipe (A) downward through the yoke and out through the discharge valve (B). Before the bowl is empty, however, and while there is enough water remaining to effectually seal the end of the pipe (A) the balancing weight on the lever causes the bowl to tilt back to its filling position and close tightly the discharge valve. This valve remains closed until the trap gathers another load of water".

The changes which were necessary for converting the separating trap into a return trap were as follows:-

(1) The pipe (A), Fig. XV, was inverted so that the open end was at the top of the bowl instead of the bottom.

(2) The support (C) was raised so that the trap would empty by gravity. This was done by simply using long bolts with separators to connect the support to the base. In order to properly locate the fulcrum for the weight lever, this support should have been moved about 1 1/2-inches toward the front end. This, however, would have required a special block between the support and the base. The desired result was accomplished by tilting the trap slightly forward, and using a tension sprin to assist the weight of the water and bowl in dumping the trap. This assistance was necessary for only a short distance at the very beginning of motion, and the spring was so connected that its tension was relieved after a slight motion of the bowl.

(3) The valve (B) was changed so as to conform to theconstruction of the valve on the return trap, by extending the valve stem through and adding an air valve at the bottom.

(4) It was also necessary to place a yoke on the projecting ring (D) for operating the valve stem; as the new position of the bowl caused the projecting ring to point downward at such an acute angle that the desired motion could not be obtained directly from it.

(5) There were two features of construction on this trap, which were not mentioned in the catalogue description of it. They were: a small hole, about 3/16 of an inch in diameter, which connected the space above the water in the bowl with the space leading to the dis-

charge trunnion; and a small pet cock on the discharge trunnion. The purpose of these was evidently to exhaust the air from the bowl in case the trap became air bound. In order to use this trap as a return trap it was of course necessary to keep the pet cock closed, and to solder up the small hole.

After these changes were made the trap worked very satisfactorily. It was, however, necessary to carry a low water line in the boiler, as the height of trap above center of gauge glass was only about two feet, and it is the usual custom to place Bundy return traps at least three feet above the water line.

Another difficulty that was encountered was the fact that when receiver No. 1 was in operation the water came down faster than the trap could handle it. This was remedied by placing a receiver between the meter and the trap. This receiver, which will be called receiver No. 2, consists of a piece of 4-inch pipe, 5 feet and 3 inches long, and having the ends closed by caps. It has a capacity of about 29 pounds of water, and is open to the atmosphere so that by no chance can the water back up and flood the meter. The temperature of the feed water is taken in this receiver.

(E) A steam separator is used to remove as much of the moisture as possible from the steam, which moisture is then conducted to a tank and weighed.

The reason for adopting this method of determining the moisture in the steam is that it is automatic, and after the percentage of moisture which the separator can be expected

to leave in the steam is determined with a fair degree of accuracy, should give very satisfactory results.

The separator which was used in test No. 1 was made up of pipe and the construction is shown in Fig. XVI. (See proposed changes)

(F) A Standard Steam trap was used in test No. 1 to seal the discharge from the steam separator. This trap has no special features and its construction is clearly shown by Fig. XVII. (See proposed changes).

A Marck steam trap was first tried but was found to be unsuited for use with low pressure steam on account of its principle of action. This trap depends for its operation upon the difference in temperature of the water flowing through the trap and the steam in the main. When the steam pressure is low this difference is evidently very slight, and hence the action of the trap was not at all satisfactory.

(G) A Schaeffer and Budenberg separating calorimeter is used to determine the moisture in the steam after it passes the separator.

On account of the low pressure of the steam it was not feasible to use the calorimeter in the usual way, because the flow through the orifice in ten minutes could not be accurately determined, and also because the amount of water separated in ten minutes was almost too small for measurement.

The method adopted was to let the calorimeter run for 20 to 30 minutes, and condense all the steam flowing through it in a can containing cold water. By weighing the can of water before and after the run, the exact amount of

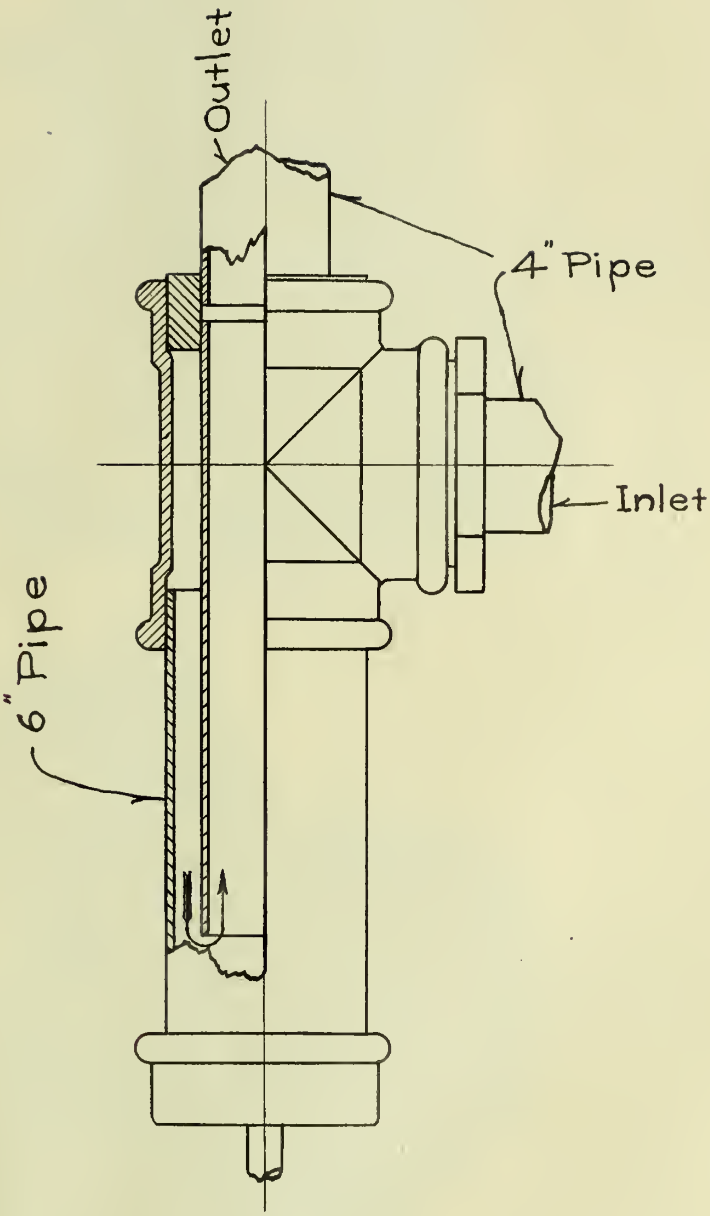



FIGURE XVI.

FIGURE XVII.

steam which has passed through the calorimeter may be determined. Care should be taken to have the steam pressure approximately the same at the end as at the beginning of the run. Fig XVIII shows the construction of the calorimeter.

(H) The main steam pipe from the boiler to the reducing valve is a 4-inch pipe covered with standard magnesia pipe covering. It contains three right angle bends, two connections to pressure gauges, one stop valve, one separator, and one calorimeter nipple. (See Fig. II) None of the other piping is at the present time covered.

The return pipe from the trap to boiler contains a by-pass, by means of which the water may be diverted at any time and weighed, to serve as a check on the meter. Beyond this connection is a bleeder which may be left open to ascertain whether there is any leakage past the valves. (See Fig. III.)

(I) There are two combined pressure and vacuum gauges, one pressure gauge, and four draft gauges used.

One of the combined pressure and vacuum gauges is a Bristol recording gauge having a range from full vacuum to 15 pounds, and is used for recording the pressure in the boiler.

The other is a Crosby gauge having a range from full vacuum to 15 pounds, and is used on the condenser. This pressure is not used in calculating the results, and simply serves to inform the operator how the condenser is working. For that reason it was not deemed necessary to calibrate the gauge.

THE SEPARATING CALORIMETER.

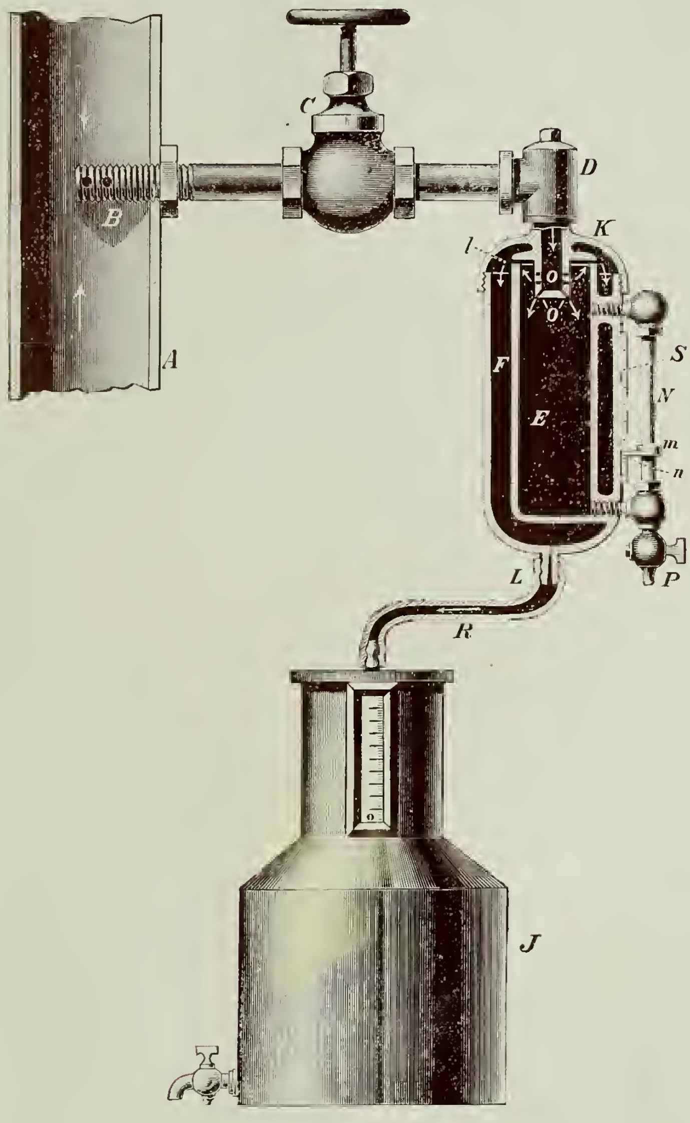



FIGURE XVIII.

The pressure gauge mentioned above is also a Crosby gauge and has a range from 0 to 30 pounds. It was carefully calibrated and the pointer set to read correctly. The test seemed to indicate, however, that the gauge readings were probably correct only to within one quarter of a pound. It is used simply as a check on the recording gauge, and takes the pressure at the same point in the steam main.

Two of the four draft gauges are Bristol recording gauges, and the other two are differential gauges made by the Appliance Manufacturing Company of Chicago. The Bristol gauges gave considerable trouble at first, the pens throwing ink over the records and persistently refusing to register correctly. Finally, however, they were adjusted so that they gave fairly satisfactory results; but the vibration of the stand for the apparatus caused an apparent fluctuation of the draft which was not actually present. The differential gauges are very accurate and may be easily read to less than 1/100 of an inch of water. They use a 300° test kerosene oil instead of water for the fluid, in order to decrease the effect of capillary attraction. Their construction is shown by Fig. XIX.

The recording pressure gauge together with the four draft gauges, and a recording thermometer are mounted on an instrument board, which is located at a convenient place for observing the different readings. The connections to the draft gauges are made with 1/4-inch wrought iron pipe. (See Fig. II).

(J) The thermometers used are: two common mercury

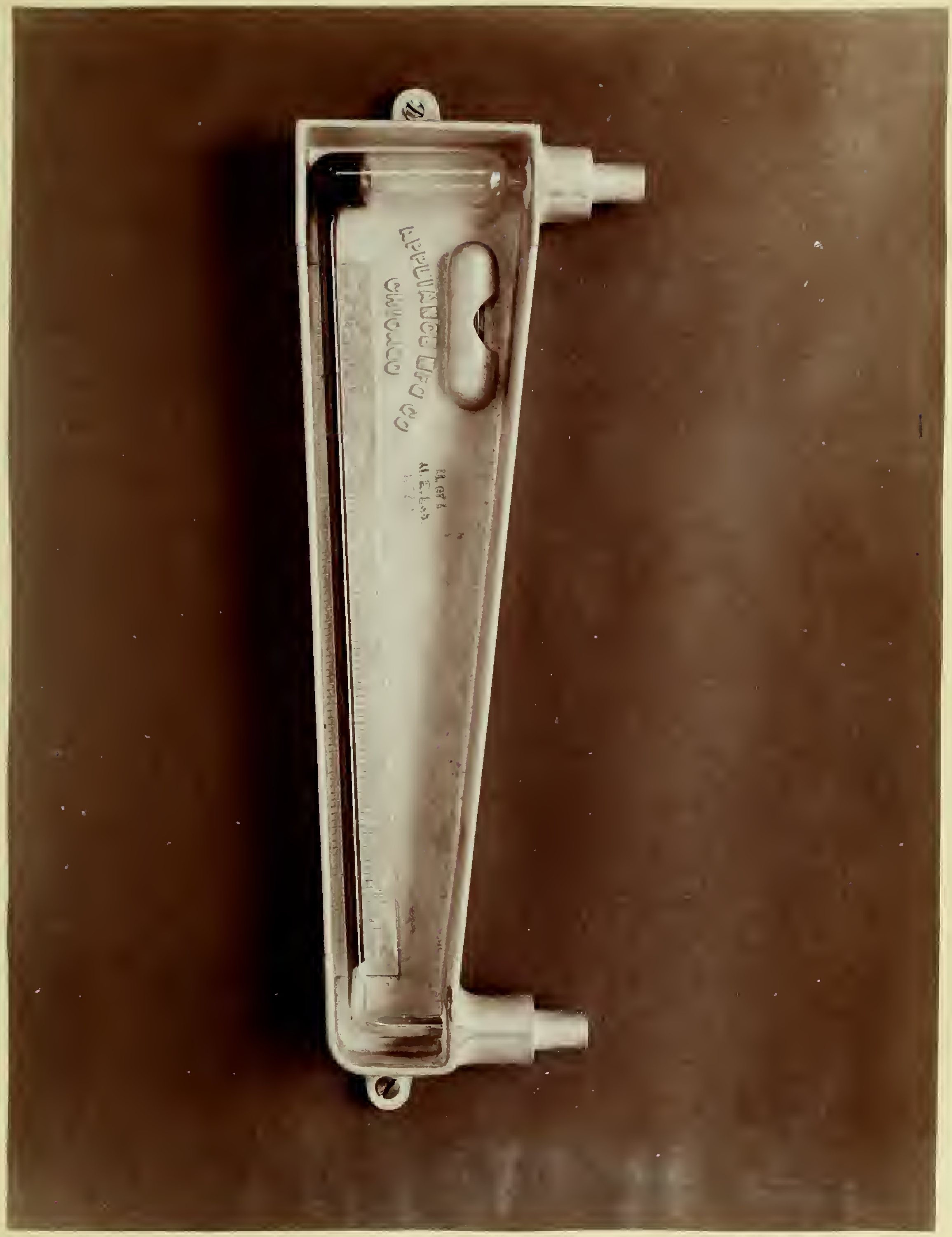



FIGURE XIX.

thermometers; one Bristol recording thermometer; and one Hartmann and Braun electrical pyrometer.

The mercury thermometers are used for taking the temperature of the feed water, and have been carefully calibrated by comparing with a standard thermometer. The errors in both cases were so small that they were entirely negligible. Thermometer No. 1 is used for taking the temperature of water returning to boiler from condenser, while thermometer No. 2 is used for taking the temperature of fresh water which is fed from the main.

The Bristol recording thermometer is used for taking the temperature of the feed water returning to the boiler from the condenser. The bulb of this thermometer is placed close to thermometer No. 1, and thermometer No. 1 is used simply for a check on its readings.

The Hartmann and Braun electrical pyrometer is manufactured in Germany, and is handled in this country by Chas. Englehardt of New York. It was used in test No. 1 for taking flue gas temperatures. The reason for using such an instrument was that when the fire was forced the flue gas temperature rose above 1000° F. which is the upper limit of the ordinary flue gas thermometers. The couple is enclosed in a piece of 1/2-inch iron pipe, one end of which is closed by a cap. The scale of the indicator is graduated in degrees Centigrade and ranges from 200° to 1600°. (See proposed changes)

(K) Three weighing tanks mounted on platform scales are used.

One of the tanks is a condensing vessel for the

calorimeter; another is used for weighing water separated from steam; and the other is used for weighing condensed steam when checking the readings of the meter.

A fourth pair of platform scales is used for weighing the coal and ash. All scales used on these tests are manufactured by the Buffalo Scale Company, and have been tested and adjusted to read correctly.

(L) Samples of the coal and ash are stored in galvanized iron cans, which have tightly fitting covers. These cans are large enough to hold a thorough sample for a 24-hour test, being about 18 inches in diameter and 30 inches high.

(M) The gas analysis apparatus consists of four leveling bottles, an Orsat apparatus, and the necessary connections. The sample is taken through a 1/4-inch iron pipe, which passes clear through the smoke pipe near the boiler. This pipe has one end closed and is perforated along its length by 1/16-inch holes, about an inch apart. It seemed reasonable to suppose that this arrangement should give an average sample of the gases all through the stack.

## METHOD OF CONDUCTING TEST

Considerable trouble has been experienced in burning bituminous coal in house-heating steam boilers, on account of the difficulty in keeping a uniform steam pressure. For that reason, it might be well to briefly mention some of the points that should be observed in burning this class of coal.

Illinois coal has a high percentage of volatile matter, and for proper combustion should have a liberal sup-

ply of air. This is most especially true just after a fresh charge of coal has been fired. In order to obtain this result the fire door should be left open about a quarter or half an inch for 15 or 20 minutes after each firing. The slide damper in fire door should be open practically all the time. It is also imperative to leave some of the live coals uncovered, so as to have sufficient heat present to ignite the volatile hydro-carbons, which are driven off from the green coal in great quantities. If these gases are not ignited they pass out of the chimney as a dense cloud of smoke, which is very objectionable in a residence neighborhood. This is also a serious loss of heat, as a large percentage of the heat contained in bituminious coal is in the volatile matter. When the outlet of the gases is at the rear end of the furnace, it is desirable to heap up the live coals at that end of the grate, and place the green coal at the front end. The volatile matter which is given off must then pass directly over the live coals, and if sufficient air is supplied should be burned very thoroughly. Care must be taken, however, not to supply too much air, as the condition which then prevails is that large quantities of air are passing through the furnace and out at the chimney, which take no active part in the combustion of the fuel, but simply absorb heat and carry it away. In this particular furnace the gases rise vertically from the grate, so that equally good results would be obtained by raking the live coals to the front of the grate, and firing the green charge behind. This method of firing being more convenient for circular fire-pot boilers, should be

adopted in these tests.

A very thick bed of coals should be carried at all times to avoid: (1) sudden changes in the condition of the fire; (2) losses due to holes in fire bed; and (3) the necessity of frequent firing. When only a slight heat is desired the grates should be well covered with ashes.

In order to determine the best method of firing for each particular coal, and to obtain thoroughly reliable results, it was decided that three tests of 24 hours duration should be run on each sample. If at the end of these tests the person in charge should consider the results incomplete, the test should be continued until satisfactory results are obtained.

An effort should be made to have the conditions in regard to the generation of steam as similar to the conditions which actually exist in house-heating as possible. It is well known that in an ordinary house-heating plant the following conditions are encountered:-

(1) When the fire is first replenished in the morning, the house is cold, and for several hours considerable steam must be generated in order to establish and maintain the desired temperature.

(2) During mid-day and most of the afternoon the heat of the sun becomes a potent factor, and considerably less steam will be required to keep the already warm house at a uniform temperature.

(3) After sun-down there is a period of several hours during which the temperature of the house must

be kept up. In order to do this with a falling outside temperature, it is evident that there must be an increase in the amount of steam generated.

(4) When the family retires for the night, the fire is banked, and the temperature of the house allowed to fall. This lowering of the inside temperature should be accomplished by turning off radiators in rooms where little heat is desired and thus reducing the radiating surface, rather than by letting the pressure fall in the boiler. The very foundation principle of heating by steam depends on the maintenance of the steam pressure, for as soon as steam ceases to be generated no heat at all is given off by the system.

A twenty-four hour day may thus be divided into four distinct periods, and an effort will be made to roughly duplicate these conditions in the tests. Two of the three tests which are to be run on each sample should be conducted under conditions which would correspond to mild weather heating. The other test should be run under forcing conditions.

The following is a statement of the conditions which will be considered standard for the tests under mild weather or average conditions:-

Test begins at 8:00 A. M.

8:00 A. M. to 1:00 P. M. 100 pounds water evaporated per hour
1:00 P. M. to 8:00 P. M. 50 pounds water evaporated per hour
8:00 P. M. to 11:00 P. M. 75 pounds water evaporated per hour
11:00 P. M. to 8:00 A. M. 25 pounds water evaporated per hour
Times of firing: 8:00 A. M.; 1:00 P. M.; 8:00 P.M.; 11:00 P.M.

Heavy fire, grate well covered with ashes

The following is a statement of the conditions which will be considered standard for the tests under forcing conditions:-

Test begins at 8:00 A. M.

8:00 A. M. to 1:00 P. M. lbs. water evap. per hr-Max. possible- 100%

1:00 P. M. to 8:00 P. M. lbs. water evap. per hr 50%

8:00 P. M. to 11:00 P. M. lbs. water evap. per hr 75%

11:00P. M. to 8:00 A. M. lbs. water evap. per hr 25%

Times of firing - every hour from 8:00 A. M. to 1:00 P. M, during other periods to suit conditions. Heavy fire - grate well cleaned.

In starting a test the plant should be in operation for at least half an hour before the beginning of a test in order to have everything in good working order. The grates should be clean and a good bed of live coals three or four inches thick should be present on the grate at the beginning of the test. A careful observation of the condition and depth of the fire should be made in order to be able to end the test with the fire in the same condition. The ash-pit should be cleaned out thoroughly, and the heating surface should have all soot, which has collected on it, thoroughly brushed off. When the test is started the regular observations should be taken, the most important of which are the condition of the fire, the reading of the water meter, the level of the water in receiver No. 1, the steam pressure in the boiler, the height of water in the gauge glass, and the

gross weight of tank for collecting water separated from the steam.

During the test the following observations are recorded automatically by the Bristol recording instruments:-

1. Steam pressure in boiler
2. Temperature of feed water
3. Draft in chimney
4. Draft in ash-pit

The following observations should be taken every hour, unless otherwise specified:-

1. The weight of each charge of coal together with the time of firing
2. Steam pressure by Crosby Gauge, to check Bristol recording gauge
3. Temperature of feed water by mercury thermometer, to check Bristol recording thermometer. (Must be taken while trap is working.)
4. Draft in chimney by differential gauge, to check Bristol recording gauge
5. Draft in ash-pit by differential gauge, to check Bristol recording gauge
6. Height of water in gauge glass
7. Weight of water separated from steam
8. Calorimeter reading
9. Analysis of flue gases
10. Temperature of flue gases
11. Temperature of the room
12. Temperature of the external air

It is hoped that the steam separator will operate with enough uniformity to make regular readings of the calorimeter unnecessary. Should this be true the moisture in the steam will be collected continuously and may be determined at end of test. The other hourly readings constitute data which are not absolutely essential, and would not need to be taken regularly for more than 12 hours of the test. From a consideration of this data it is evident that one man alone could conduct a 24-hour test, and between 8:00 P. M. and 8:00 A. M. would not be required to give the plant any attention, except at eleven o'clock while fixing the fire and regulating the apparatus for the night run.

Samples of coal should be taken from the barrow at each firing, and placed in the air tight sampling can. After the test is completed this sample should be quartered down until an average sample of about a quart is obtained. This sample should then be sealed in a fruit jar and turned over to the chemistry department for analysis.

At the end of the test the ash which has fallen through the grates and the clinker which has been removed through the clinker door should be separately weighed. From these weights the percentage of clinker in the ash may be determined. The clinker should then be broken up and thoroughly mixed with the free ash. The whole amount of free ash and clinker should then be quartered down, and a quart sample sent to the chemistry department for analysis. Care should be taken to have the ash perfectly dry when the weights are obtained.

The composition of the flue gases should be determined during about 12 hours of the test. When this is done the operator should be able to estimate the proportions with a fair degree of accuracy for the rest of the test. A sample should be taken, by means of a pair of leveling bottles, from the sampling tube in the smoke pipe. While taking this sample the gas should be admitted to the sampling bottle at a uniform rate for a period of one hour. This set of leveling bottles should then be removed and the other set started on a second sample. In order to insure the removal of all the air from the connections, a quantity of the gas should be drawn into the sampling bottle and then discharged to the atmosphere before the sample is started. The solution used in the leveling bottles should be a saturated brine solution. Pure water should not be used on account of its affinity for $CO_2$. This property would very seriously affect the results, for the water would act as a $CO_2$ sponge, absorbing it when the gas contained a large quantity and liberating it when only a small amount was present. The percentages by volume of $CO_2$, O, and CO contained in the sample should then be determined by means of an Orsat apparatus. Care must be taken to keep the absorbing solutions fresh, especially the pyrogallic acid, which is used for absorbing the free oxygen.

It was found that when the boiler was being run at about its maximum capacity, the temperature of the escaping flue gases was above 1000° F., a fact which would seem to indicate either that the amount of heating surface was insufficient or that the rating of the boiler was too high.

No smoke or soot observations were taken during test No. 1. (See proposed changes).

In closing the test great care should be taken to have the fire in the same condition as at the start. It is also desirable to have other conditions the same, but the fire is the most important, as an error of one pound in the coal is equivalent to an error of about seven pounds in the water. The test should be started and stopped at a time when the trap is not feeding the boiler.

DATA AND RESULTS OF TEST NO. 1 MADE AT THE MECHANICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS

By John J. Harman April 26-27, 1906

ARCO BOILER NO. 1-28-S

| | |
|---|---|
| 1. For dimensions and proportions, see page ------ | 7 |
| 2. Duration of trial -------------------- hrs-min | 23-45 |
| **Average Pressures** | |
| 3. Steam pressure in boiler---Lbs. per square inch | 4 |
| 4. Force of draft between damper and boiler inches of water | .24 |
| 5. Force of draft in ash-pit ----- inches of water | .01 |
| **Average Temperatures** | |
| 6. Of external air ----------------- degrees Fahr | 78 |
| 7. Of laboratory ------------------ degrees Fahr | 84 |
| 8. Of feed water entering boiler ---- degrees Fahr | 85-72 |
| 9. Of escaping gases from boiler ---- degrees Fahr | (Max. 536<br>(Ave. |
| **Fuel** | |
| 10. Size and condition -------------------------- | Pea |

| | | |
|---|---|---|
| 11. Weight of coal as fired -------------- pounds | | 367 |
| 12. Percentage of moisture in coal ------ per cent | | 14.35 |
| 13. Total weight of dry coal consumed ----- pounds | | 314 |
| 14. Total ash and refuse ----------------- pounds | | 41 |
| 15. Quality of ash and refuse, in percentage of clinker | | 0 |
| 16. Total combustible consumed ----------- pounds | | 273 |
| 17. Percentage of ash and refuse in dry coal ----% | | 13.05 |

Proximate Analysis of Coal

| | Percent of coal | % of Combus. |
|---|---|---|
| 18. Fixed carbon | 39.52 | 54.50 |
| 19. Volatile matter | 33.00 | 45.50 |
| 20. Moisture | 14.35 | |
| 21. Ash | 13.13 | |
| | 100.00 | 100.00 |
| 22. sulphur separately determined | 2.9 | 4.0 |

Analysis of Ash and Refuse

| | |
|---|---|
| 23. Carbon ---------------------------- per cent | 11.05 |
| 24. Earthy matter --------------------- per cent | 88.14 |
| 25. Moisture -------------------------- per cent | .81 |
| | 100.00 |

Fuel per Hour

| | |
|---|---|
| 26. Dry coal consumed per hr.8:00A.M.-1:00P.M.lbs. | 19.8 |
| 27. Dry coal consumed per hr.1:00P.M.-8:00P.M.lbs. | 15.2 |
| 28. Dry coal consumed per hr.8:00P.M.11:00P.M.lbs. | 14.0 |
| 29. Dry coal consumed per hr.1100P.M.-8:00A.M.lbs. | 7.5 |
| 30. Dry coal consumed per hr. ------------ pounds | 13.2 |
| 31. Combustible consumed per hour --------- pounds | 11.5 |
| 32. Dry coal per sq. ft. grate surface per hr.lbs. | 3.3 |

| | | |
|---|---|---|
| 33. Combustible per sq.ft.water heating surface per hour | pounds | .27 |

Calorific Value of Fuel

| | | |
|---|---|---|
| 34. Calorific value of fuel by oxygen calorimeter per lb. of dry coal | B.T.U. | 10632 |
| 35. Calorific value of fuel by oxygen calorimeter per lb. of combustible | B.T.U. | 14100 |

Quality of Steam

| | | |
|---|---|---|
| 36. Percent of moisture in steam leaving separator | | 1.5 |
| 37. Amount of water separated from steam in separator | pounds | 18.5 |
| 38. Percent of moisture in steam leaving boiler | | 2.7 |
| 39. Quality of steam leaving boiler (dry steam = unity) | | .973 |

Water

| | | |
|---|---|---|
| 40. Total water fed to boiler | pounds | 1250 & 78 |
| 41. Water actually evaporated corrected for quality of steam | pounds | 1090 & 78 |
| 42. Factor of evaporation | | 1.13&1.15 |
| 43. Equivalent water evaporated into dry steam from and at 212 degrees | pounds | 1235 & 90 |

Water per hour

| | | |
|---|---|---|
| 44. Water evaporated per hour corrected for quality of steam | pounds | 49 |
| 45. Equivalent evaporation per hour from and at 212 degrees 8:00 A. M. to 1:00 P. M. | | |
| 46. 1:00 P. M. to 8:00 P. M. | | |
| 47. 8:00 P. M. to 11:00 P. M. | | |
| 48. 11:00 P. M. to 8:00 A. M. | | |
| 49. Equivalent evaporation per hour from and at 212 degrees | pounds | 56 |
| 50. Equivalent evaporation per hour from and at 212 degrees per square foot of water-heating surface | pounds | 1.67 |

| | |
|---|---|
| 51. Capacity developed per hour of test, square feet radiating surface (.26 lbs. water condensed per square foot of radiating surface per hour ------------------------------------------ | 189 |
| 52. Maximum capacity for 1 hour ------ square feet | 542 |
| 53. Catalogue rating ----------------- square feet | 800 |

## Economic Results

| | |
|---|---|
| 54. Water apparently evaporated per pound of coal as fired ------------------------------------ | 3.18 |
| 55. Equivalent evaporation from and at 212 degrees per pound of coal as fired ------------------ | 3.6 |
| 56. Equivalent evaporation from and at 212 degrees per pound of dry coal------------------------ | 4.2 |
| 57. Equivalent evaporation from and at 212 degrees per pound of combustible -------------------- | 4.85 |

## Efficiency

| | |
|---|---|
| 58. Efficiency of the boiler; heat absorbed by the boiler per pound of combustible, divided by the heat value of 1 lb. of combustible per cent | 33 |
| 59. Efficiency of boiler, including the grate;heat absorbed by the boiler per pound of dry coal, divided by the heat value of a pound of dry coal ----------------------------------------- | 38 |

## Cost of Evaporation

60. Cost of coal per ton of 2000 pounds delivered in boiler room ---------------------- dollars

61. Cost of fuel for evaporating 1000 pounds of water under observed conditions ----- dollars

62. Cost of fuel for evaporating 1000 lbs. of water from and at 212 degrees ------------- dollars

## Smoke Observations

63. Ringelman smoke chart,----- -----------Number

64. Weight of soot collected on copper bar -- lbs.

## Method of Firing

| | | |
|---|---|---|
| 65. Kind of firing ------------------------------------ | | coking |
| 66. Average thickness of fire ------------- | inches | 10 |
| 67. Average interval between firings--------- | hours | 2.15 |
| 68. Longest interval between firings ------- | hours | 9.75 |

## Analysis of the Dry Gases

| | | |
|---|---|---|
| 69. Carbon dioxide ($CO_2$) ----------------- | per cent | 4.5 |
| 70. Oxygen (O) --------------------------- | per cent | 13.7 |
| 71. Carbon monoxide (CO) ----------------- | per cent | .3 |

## METHOD OF CALCULATING RESULTS

The calculations involved in working up the results of one of these tests are almost precisely the same as those encountered in working up a power plant boiler test by the A. S. M. E. code for boiler testing. A few items have been omitted which did not apply to this type of boiler, and a few additional ones have been inserted which did seem to be necessary.

The method of finding the average temperatures and pressures from the Bristol recording instrument charts is to planimeter the area inside the curve, and find its mean radius. Then lay off the radius from the center of the chart, and read the mean temperature or pressure as the case may be. Figs. XX, XXI, XXII, and XXIII show the records obtained in Test No. 1.

The College of Engineering possesses quite an extensive assortment of different kinds of computing machines, which are all available for use on work of this kind.

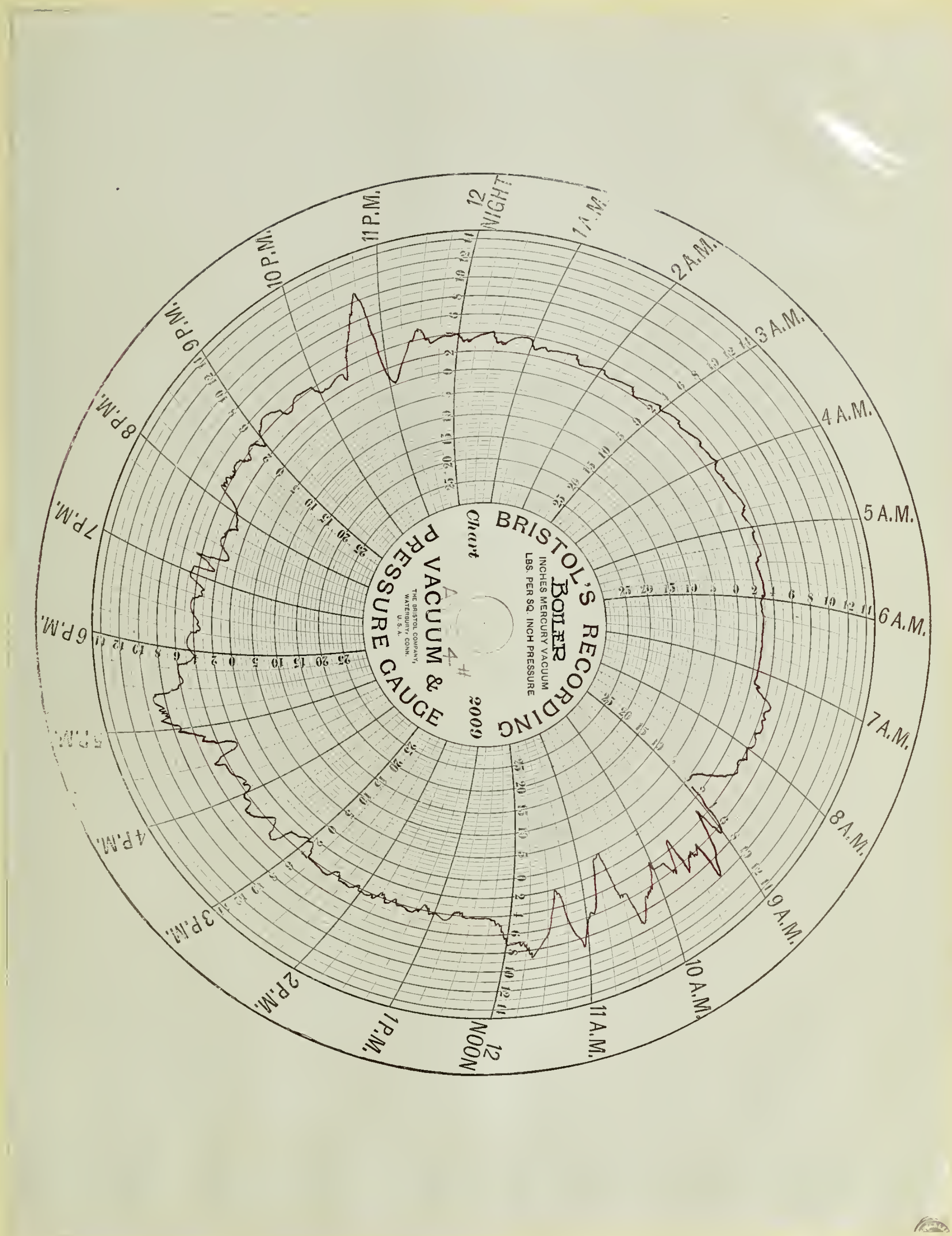

BRISTOL'S RECORDING
BOILER
VACUUM &
PRESSURE GAUGE
INCHES MERCURY VACUUM
LBS. PER SQ. INCH PRESSURE
Chart 2009
THE BRISTOL COMPANY,
WATERBURY, CONN.
U. S. A.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.

FIGURE XX.

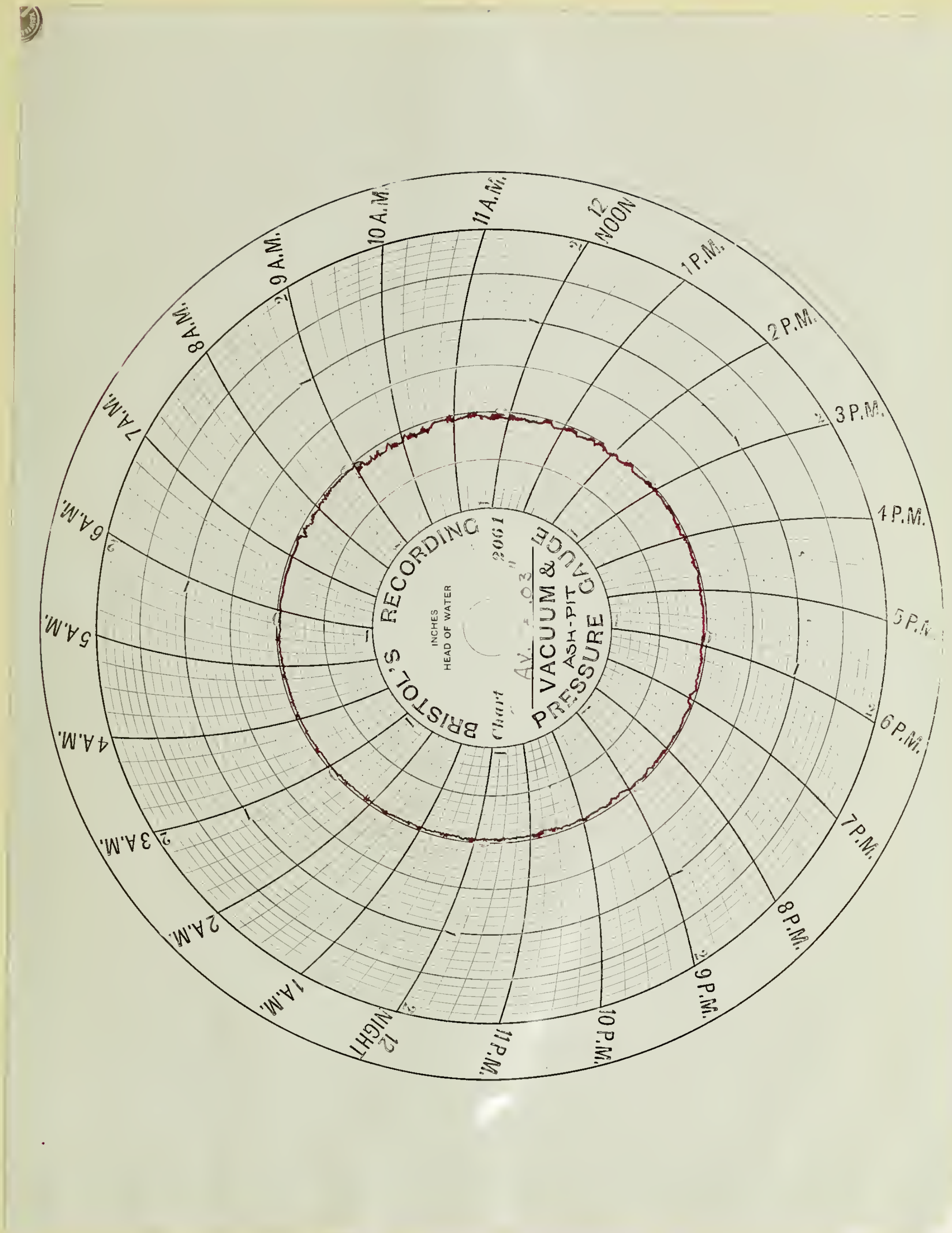

BRISTOL'S RECORDING
VACUUM & PRESSURE GAUGE
ASH-PIT
INCHES HEAD OF WATER
Chart 2061
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.

FIGURE XXI.

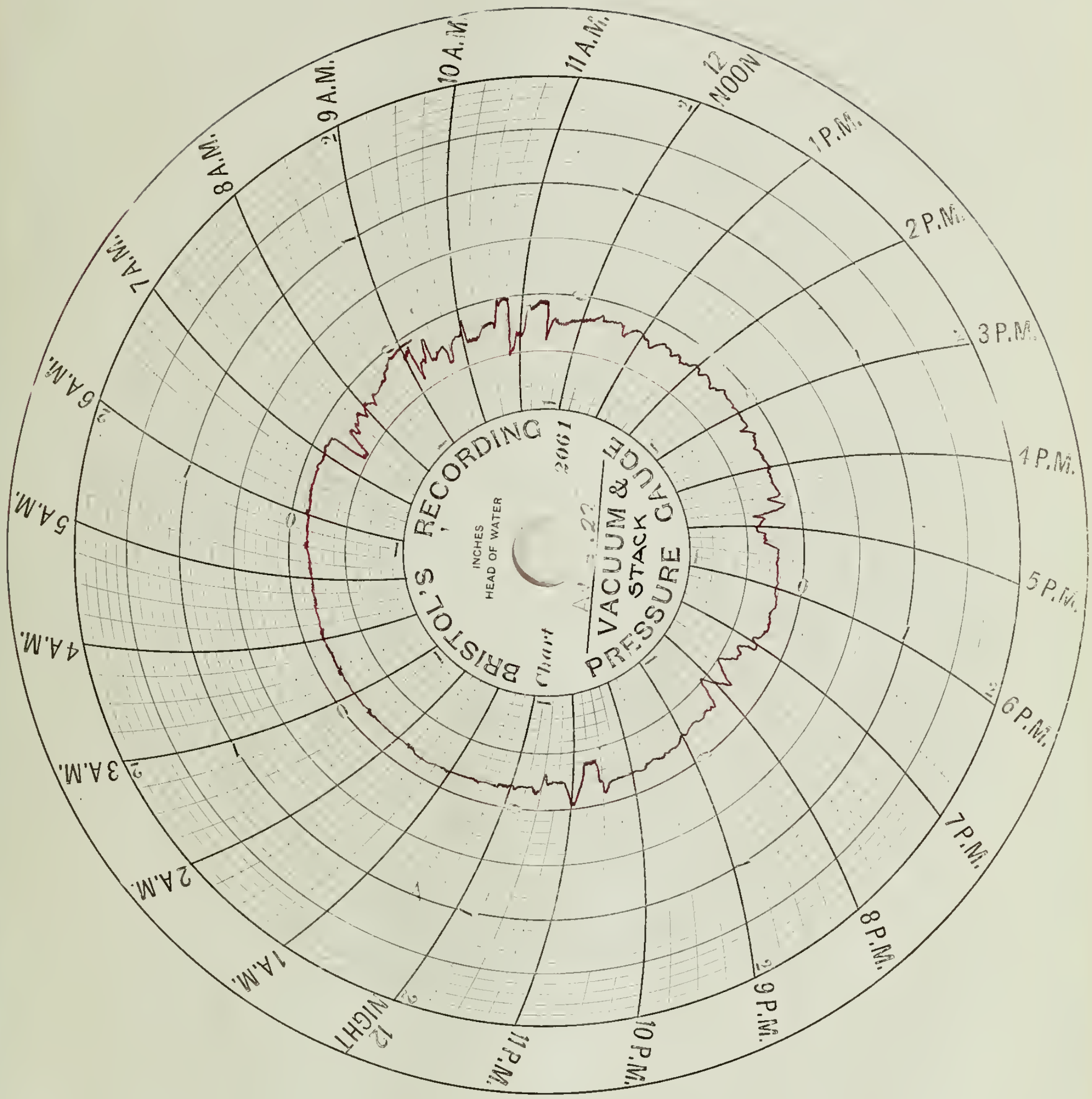

BRISTOL'S RECORDING
VACUUM & STACK PRESSURE GAUGE
INCHES HEAD OF WATER
Chart 2061
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.

FIGURE XXII.

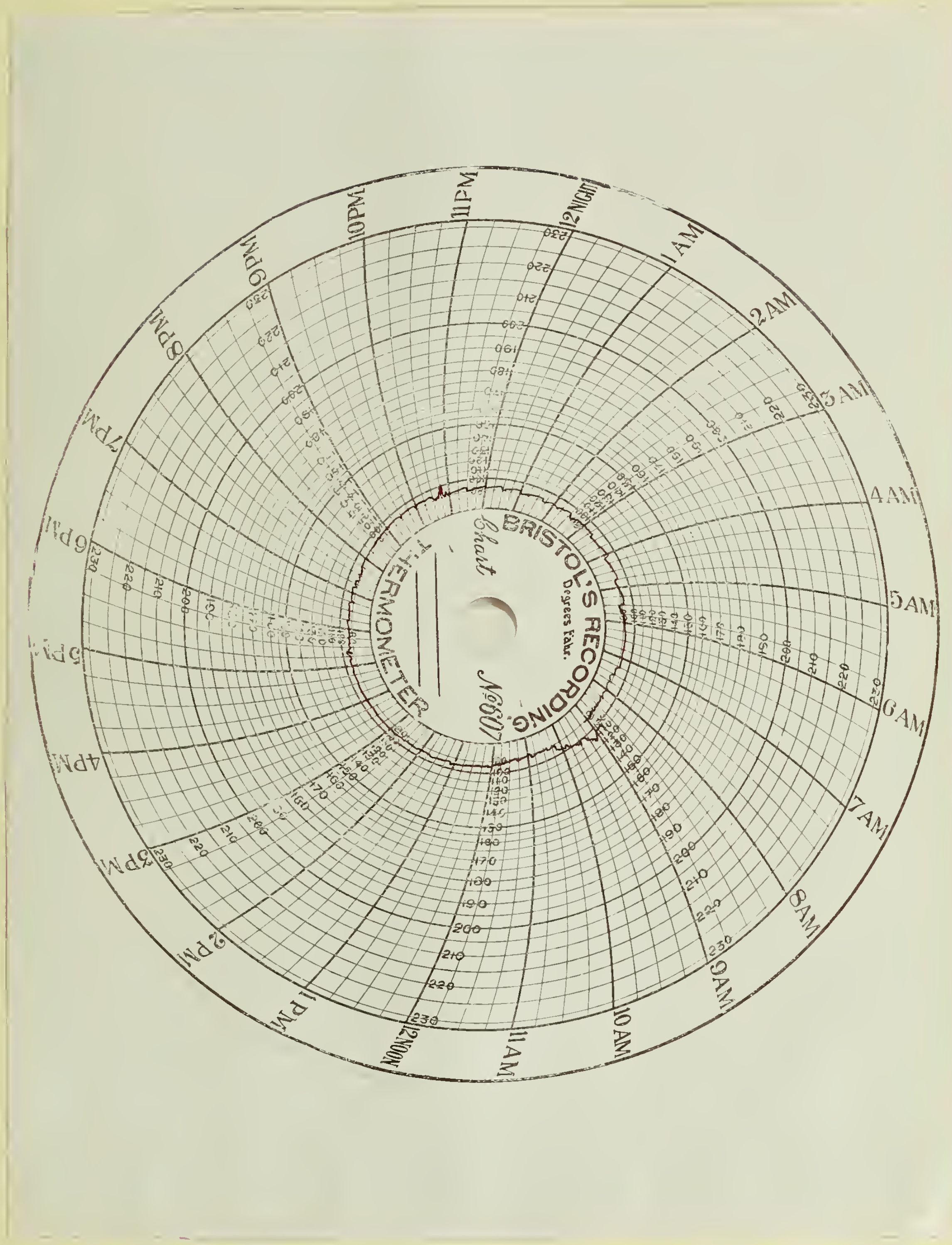



FIGURE XXIII.

## CONCLUSION

The apparatus was operated for a sufficient length of time to determine its defects. A number of these defects were remedied, and have been previously discussed in this thesis. A few changes in the apparatus and method of conducting the tests, however, were not carried out on account of lack of time, and these will simply be enumerated and discussed below:-

(1) Better economic results would be obtained by lagging the boiler, the live steam pipe leading to the Bundy trap, and the return pipe from the trap to the boiler.

(2) The ultimate analysis of the coal should be obtained for all future tests, as results based on the proximate analysis are of little value. This point is well illustrated in Test No. 1, where the efficiency of boiler and grate combined was found to be 38 per cent, and the efficiency of the boiler alone was only 33 per cent, these results being based on the proximate analysis of the coal.

(3) No smoke observations were taken during Test No. 1, on account of the inconvenience in observing the top of the chimney. Before the tests are continued a sky-light should be placed in the roof at a convenient point for observing the smoke.

Soot observations should also be taken, in a manner similar to that recommended in appendix No. XXXIV to the A. S. M. E. code of 1899. However, the bar should be placed in the heating surface region of furnace between the fire-pot section and the section above it, instead of being placed in

the flue; and it should be allowed to collect soot during the entire 24-hour test, instead of being removed every two hours. This would furnish a very fruitful method of comparison between the different coals, for it is a well know fact that soot deposits on the heating surface very seriously reduce the transmission of heat.

(4) The smoke hood check draft should be connected to the lever arm of the damper regulating device, in order to assist in regulating the fire. That very good regulation, however, was obtained in test No. 1 without using the check draftat all, is shown by the pressure chart, Fig. XX. It will be noted that the pressure remained almost exactly 3 pounds for a period of seven hours, from 12 o'clock midnight to 7 o'clock in the morning. During that time the fire was regulated entirely by the damper regulatin device, as no one was present in the Laboratory.

(5) The pyrometer which was used in test No. 1 for obtaining the flue gas temperatures was not very well suited to the purpose for several reasons:-

1. It is a very delicate instrument, and danger of breakage is very great around an apparatus of this kind.

2. It reads in Centigrade degrees, and all the readings have to be reduced to Fahrenheit units by a laborious calculation.

3. The scale is not graduated below 200° C. or 392° F., and the temperature of the flue gases is often below this when the fire is low.

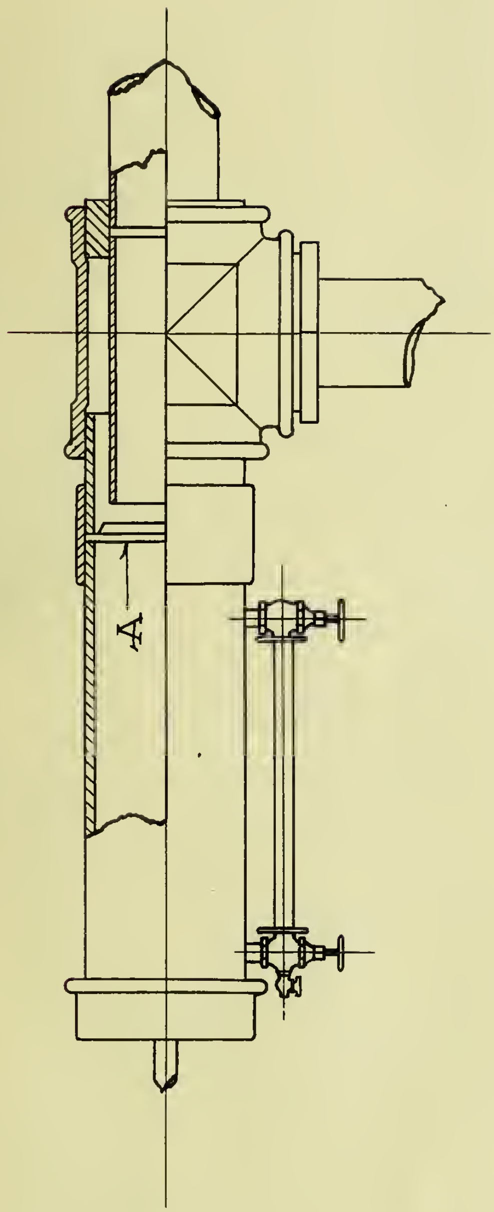
For these reasons I recommend the purchase of a low resistance pyrometer, made by the Wm. H. Bristol Pyrometer Co., of New York. The galvanometer for indicating the tempertures is not of the suspension type, and consequently will stand much rougher usage. This indicator could be mounted on the instrument board along with the other instruments, and in that location would be much more convenient to read. It has a Farhrenheit scale which extends from 200 to 2000 degrees.

(6) All water fed to the boiler should, hereafter, be fed through the trap, and should pass through the meter. Piping should be arranged to supply fresh water to receiver No. 1 when it is necessary to raise the water line in the boiler. The readings of the meter will then give the total amount of feed water supplied to the boiler.

(7) I recommend a change in the construction of the steam separator in order to make it more effective in extracting moisture, and also to introduce a new method of measuring the water separated. The proposed change is clearly shown by the drawing, Fig. XXIV.

With the new separator the water may be measured by reading the difference in level on the gauge glass, or it may be drawn off and weighed. In either case, the use of a trap would be entirely unnecessary, as the receiver of the separator would have sufficient capacity for a run of several hours.

(8) In view of the fact that it has previously required two steam pumps and an intermediate tank to handle the



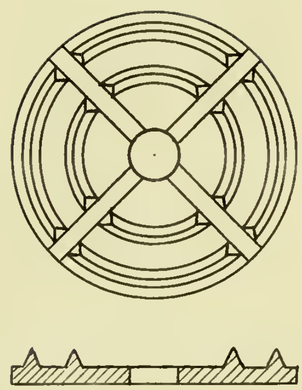



Plate A

FIGURE XXIV

cooling water for the condenser, I propose that a small centrifugal pump be used hereafter. The centrifugal pump should be able to maintain the suction, after it is once established, no matter how much the delivery may be throttled.

(9) When receiver No. 1 was a ed to the apparatus the water leg was lengthened 21 3/4 inches, so that the scale alongside the gauge glass is in error by that amount. This should be corrected.

(10) In test No. 1 it was impossible to force the boiler without flooding receiver No. 2 and causing it to overflow. This defect was due to the length of siphon in receiver No. 1. The siphon was 4-inches long, and this length held back the water until approximately 22 pounds had collected. It then discharged the 22 pounds together with whatever water flowed into the receiver during the discharge.

Calculating the amount of water discharged and time required for discharging, when the condenser is operating at the rate of 200 pounds of water per hour (the rated capacity of the boiler), we obtain;-

Known data:

| | |
|---|---|
| Pounds water flowing into receiver No. 1 per hour | 200 |
| Pounds water flowing into receiver No. 1 per minute | 3 1/3 |
| Pounds water flowing out of receiver No. 1 per hour | 416 |
| Pounds water flowing out of receiver No. 1 per minute | 6.95 |

Let x = total weight of water discharged from receiver No. 1 and y = time of discharging in minutes

Then:-

$$22 + 3\ 1/3\ y = x$$

$$6.95\ y = x$$

$$22 + 3\ 1/3\ y = 6.95\ y$$

$$y = 6.1 \text{ minutes}$$

$$x = 42\ 1/4 \text{ pounds}$$

Receiver No. 2 was installed to collect the surplus water and store it until the trap should have time to return it to the boiler. The capacity of this receiver is about 29 pounds of water. The maximum rate at which the Bundy trap can handle the water is probably about 250 pounds per hour. Although it appears, from this calculation that the receiver should not overflow, it is very likely to on account of the intermittent action of the trap. To illustrate: suppose the trap is almost ready to dump when receiver No. 1 begins to discharge; the trap then dumps and loses about two minutes in discharging water which has been previously collected, in the mean time the water is rapidly filling receiver No. 2 and finally overflows.

To remedy this defect the siphon should be shortened to two inches. Then the amount of water collected before discharge takes place is reduced to 11 1/2 pounds.

And $y = 3$ minutes

and $x = 21$ pounds

This change was made and an entirely new siphon was used. As the new siphon may affect the velocity of discharge, the meter should be recalibrated.

If receiver No. 2 should still give trouble under forcing conditions, the entire stand, which supports the ap-

paratus, should be raised some 12 or 15 inches in order to give the Bundy trap more head above the water line of boiler and make it discharge more rapidly.

-o-o-o-o-o-o-o-

When these changes have been carried out the apparatus should be capable of adjustment to suit any desired condition. The method of conducting the tests will be almost entirely automatic, and satisfactory results should be obtained with very little attention.